



# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2477

INVESTIGATION OF THE AIR-COMPRESSION PROCESS DURING DROP  
TESTS OF AN OLEO-PNEUMATIC LANDING GEAR

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## SUMMARY

A brief study has been made to evaluate the importance of the type of air-compression process on the loads produced on an oleo-pneumatic landing gear during impact and to determine the type of air-compression process actually obtained during drop tests. The data used in this investigation were obtained in tests of a small landing gear with dropping weights ranging from 1500 to 2500 pounds. Vertical contact velocities ranging from 0 to 11 feet per second were obtained during these tests. A simplified analysis to determine the effect which different air-compression processes might have indicates that the value of the air-compression exponent should have relatively little effect on the landing-gear loads throughout most of the impact. Near the end of the impact, however, differences in the air-compression process may have some effect on the total load, the effect depending on the extent to which increases in the polytropic exponent cause reductions in maximum strut stroke. The analysis of experimental data obtained in these tests showed that the polytropic exponent ranged from 1.01 to 1.10 for the conditions tested. For the practical range of vertical velocities the polytropic exponent appears to be essentially independent of vertical velocity. The air-compression process in these tests can be adequately represented by an average value of the polytropic exponent equal to 1.06.

## INTRODUCTION

In various papers dealing with the design of landing gears some investigators, in calculating the pneumatic spring force, have assumed the air-compression process to be virtually adiabatic, some have assumed the process to be isothermal, and still others have considered some intermediate polytropic process. This divergence of opinion may be due to the fact that experimental data regarding the air-compression process in shock struts are not found in the available literature.

In order to provide some information on the subject, measurements of air pressure and strut stroke which were obtained in tests of a small landing gear in the Langley impact basin have been analyzed. The present paper briefly discusses the extent to which the total loads on the landing gear might be influenced if different air-compression processes could occur. The main purpose of the paper, however, is to present values for the polytropic exponent actually obtained in drop tests. The experimental values of the polytropic exponent were determined from 30 impacts; the tests covered dropping weights ranging from 1500 to 2500 pounds and vertical contact velocities ranging from 0 to 11 feet per second.

### SYMBOLS

$p_a$	average pressure in outer chamber, pounds per square inch
$p_h$	average pressure in lower chamber, pounds per square inch
$p_o$	initial strut inflation pressure, pounds per square inch
$A_a$	total cross-sectional area of inner cylinder, square inches
$A_h$	inside cross-sectional area of inner cylinder, square inches
$s$	strut stroke, inches
$F$	force, pounds
$v$	air volume, cubic inches
$n$	exponent used in gas law for polytropic expansion
$V_{vO}$	vertical contact velocity, feet per second

### Subscripts:

$T$	total
$f$	friction
$o$	initial

## APPARATUS

## Equipment

The basic piece of equipment used in the present investigation is the Langley impact-basin carriage (reference 1) which provides means for effecting the descent of the test specimen under controlled conditions while the carriage is either stationary or moving horizontally. A description of this equipment and its adaptation to the testing of landing gears is given in reference 2. In the present case, the carriage was restrained in the horizontal direction and used in much the same way as a conventional landing-gear testing machine.

## Test Specimen

The landing gear tested was originally designed for a small single-engine military training airplane of the tail-wheel type having a gross weight of approximately 5000 pounds. The gear is of conventional cantilever construction and incorporates a standard oleo-pneumatic shock absorber. A single leg of the half-fork type connects the shock strut and the axle. The wheel is fitted with a 27-inch smooth-contour tire which is inflated to normal operating pressure of 32 pounds per square inch. The weight of the landing gear, including wheel and tire, is 150 pounds. A view of the landing gear attached to the boom of the impact-basin carriage is shown in figure 1. The internal arrangement of the strut is shown in figure 2.

In the fully extended position of the strut, the inside dimension measured from the top of the outer cylinder to the bottom end plate of the inner cylinder is approximately  $23\frac{3}{4}$  inches. In this position the orifice plate is  $7\frac{1}{2}$  inches above the end plate of the inner cylinder and the normal fluid level is 8 inches above the orifice plate. The internal configuration of the strut limits the maximum strut stroke to  $7\frac{3}{8}$  inches. The compression ratio, based on the air volume in the fully extended position and the air volume in the static position ( $1\frac{1}{8}$ -inch strut extension), is 4.92.

## Instrumentation

Description.- Measurements of pneumatic pressure, hydraulic pressure, strut stroke, upper-mass acceleration, and vertical contact velocity were used in the present investigation.

Pressure gages of the electrical-strain-gage type having a high natural frequency were used to measure the pressure in the upper chamber at two locations. As illustrated in figure 2, one of the upper-chamber pressure taps (item 26) was located near the upper surface (downstream face) of the orifice plate. In this case pressure near the upper surface of the orifice plate was transmitted to a pressure gage by means of an oil-filled tube having an outside diameter of 0.09 inch and a wall thickness of 0.015 inch (item 27). This tube extended from the top of the strut to the orifice plate where two rows of three 0.031-inch-diameter holes were drilled in the tube approximately  $1/8$  inch from the plate. An additional measurement of upper-chamber pressure was made by means of a pressure tap screwed into the filler plug hole (item 28) in the top of the strut after the strut was filled with fluid. Pressure in the lower chamber was measured by means of item 3 and item 22, as shown in figure 2. These pressure taps were included primarily for another investigation; however, the pressure measurements obtained from the lower-chamber pressure tap were used herein to obtain the hydraulic force. The pressures measured at the top of the strut and near the upper surface of the orifice plate are hereinafter referred to as the up-oleo and up-orifice pressures, respectively. The pressure gages were mounted in a convenient position external to the strut and were connected to the pressure tube outlets on the strut with  $\frac{1}{4}$ -inch-outside-diameter tubing having a wall thickness of  $1/32$  inch.

The strut-stroke measurements were obtained by means of a variable-resistance slide-wire potentiometer. As shown in figure 1, the base of the slide-wire unit was mounted on the landing-gear yoke and the rod which actuated the sliding contact was attached to the outer cylinder.

Measurements of the upper-mass acceleration were obtained from an accelerometer mounted on the boom of the impact-basin carriage. This accelerometer was of the unbonded-electrical-strain-gage type having a natural frequency of 85 cycles per second and was oil-damped to about 65 percent of critical damping.

An elemental voltage generator, consisting of a permanent magnet which was attached to the boom and which moved past a coil fixed to the carriage, was used to determine the vertical velocity of the landing gear at the instant of ground contact.

The measurements of pressure, stroke, acceleration, and contact velocity were recorded by an oscillograph equipped with galvanometers damped to approximately 65 percent of critical damping. The galvanometers used for the measurements of pressure, stroke, and acceleration had a natural frequency of 100 cycles per second; whereas the galvanometer

used for the vertical-velocity measurements had a natural frequency of 1650 cycles per second. The oscillograph records contained  $\frac{1}{100}$ -second timing lines. A sample oscillograph record is shown in figure 3.

Precision of measurements.- The question of instrument lag has been considered, and the effect of lag on the results was judged small enough to be unimportant. The measurements used in the present investigation are believed to be accurate within the following limits:

Pressure, pounds per square inch . . . . .	±20
Strut stroke, inches . . . . .	±0.10
Acceleration, g . . . . .	±0.10
Vertical contact velocity, feet per second . . . . .	±0.10

#### TEST PROCEDURE

The data employed in the present investigation were obtained during a general landing-gear drop-test investigation carried out in the Langley impact basin. Several series of impacts were made with dropping weights ranging from 1500 to 2500 pounds and simulated wing lift ranging from the free-fall to the fully airborne condition. Contact velocities ranging from 0 to 11 feet per second were obtained by varying the dropping height of each drop in a series.

The strut was inflated with sufficient air pressure for each dropping weight to produce the static strut clearance of  $1\frac{1}{8}$  inches specified for this landing gear. The strut was checked before each drop to insure full initial strut extension and the correct initial pneumatic pressure.

#### EVALUATION OF PNEUMATIC-PRESSURE MEASUREMENTS

In the present investigation the pressure in the outer chamber was measured because this particular pressure is the pneumatic pressure which contributes to the total force on the landing gear, as can be seen from the following equation for the total force:

$$F_T = p_a A_a + (p_h - p_a) A_h + F_f$$

where  $p_a A_a$  may be considered the pneumatic force,  $(p_h - p_a) A_h$  may be considered the hydraulic force, and

$p_a$       average pressure in outer chamber  
 $p_h$       average pressure in lower chamber  
 $A_a$       total cross-sectional area of inner cylinder  
 $A_h$       inside cross-sectional area of inner cylinder  
 $F_f$       friction force between the telescoping cylinders

In many cases it would be more convenient, and perhaps necessary, to measure the pneumatic pressure through the filler-plug hole which leads into the inner chamber. In the event of a significant pressure drop across the openings (item 6 in fig. 2) in the piston supporting tube (item 8), however, the pressures in the inner and outer chambers would not be the same. Therefore, in addition to the pressure measurements taken in the outer chamber (up-orifice pressure), pressure measurements were also obtained at the filler-plug location (up-oleo pressure) for comparison with the outer-chamber pressure.

In all cases an irregular increase in up-oleo pressure was noted in contrast to the regular increase in the up-orifice pressure during the early stage of the impact, as can be seen from the oscillograph record in figure 3. Since the up-oleo-pressure tap is located inside the piston supporting tube, the irregular pressure rise recorded may be due to the dynamic pressure of the fluid jet impinging on the pressure tap. Since these differences in recorded pneumatic pressure existed only during the early stages of the impacts where the air pressure contributes relatively little towards the total pressure forces, negligible differences were obtained in the total pressure forces computed by using either the up-orifice- or up-oleo-pressure measurements.

The up-oleo pressure was found to deviate greatly from the polytropic law of air compression during the irregular pressure rise in the early stages of the impacts; whereas the up-orifice pressure closely followed the polytropic law. This situation existed even when attempts were made to fair out the high-frequency irregularities in the up-oleo-pressure time histories. In view of these irregularities, the up-orifice-pressure measurements were used in the present investigation.

## RESULTS AND DISCUSSION

Importance of the Type of Air-Compression Process  
on Landing-Gear Loads

The effect of differences in the type of air-compression process on the total landing-gear force can be briefly examined by applying to an experimental variation of total force the differences in the pneumatic force which result when various air-compression processes are considered. In order to calculate these effects, it is assumed that the time history of strut stroke and hydraulic force in an impact remains unchanged for different assumed air-compression processes. This approach is not exact, but the calculated changes in total force should be larger than the actual changes which would occur. This approach, therefore, can be used to provide a limiting case from which conclusions regarding the importance of the type of air-compression process can be drawn.

Portions of typical time histories of pneumatic pressure and strut stroke are presented in figure 4. In figure 5 the corresponding experimental values of total force, hydraulic force  $(p_h - p_a)A_h$ , and pneumatic force  $p_a A_a$  computed from measurements of upper-mass acceleration, hydraulic pressure, and pneumatic pressure, respectively, are plotted against strut stroke and are represented by solid curves. The dashed curves in figure 5 represent variations of pneumatic force and total force which result when the air is compressed according to several different air-compression processes. The pneumatic pressures were computed for various values of the air-compression exponent  $n$  by substituting measured values of strut stroke into the pressure-volume relationship for a polytropic process

$$p_a = p_o \left( \frac{v_o}{v_o - sA_a} \right)^n \quad (1)$$

where  $p_o$  is the initial strut inflation pressure and  $v_o$  is the initial air volume. The pneumatic force was obtained by multiplying the pneumatic pressure by the air-supporting area  $A_a$ . The dashed curves for the total force were obtained by adding to or subtracting from the experimental values of total force the differences between the experimental pneumatic force and the pneumatic force calculated for the different polytropic processes.

It can be seen from figure 5 that, during the early part of the impact up to and including the instant of maximum landing-gear load, the pneumatic force contributes a relatively small amount of the total



force on the landing gear. This result is due to the fact that the maximum landing-gear load occurs at small values of strut stroke which produce only relatively small increases in pneumatic pressure. Therefore, as can be seen from figure 5, the type of air-compression process has very little effect upon the total force up to and including the point of maximum landing-gear load. Beyond the maximum load, where large strokes are obtained, different air-compression processes may result in appreciable differences in total force since the force due to compression of the air is a large percentage of the total force. For actual impacts, however, differences in the air-compression process would probably produce smaller differences in total force than those shown in figure 5 because such changes in the air-compression process would be expected to produce smaller strut strokes for the higher values of the polytropic exponent.

From these brief considerations differences in the air-compression process appear to have relatively little effect on the total loads on the landing gear during most of the impact. Near the end of the impact, however, differences in the air-compression process may have some effect on the total load, the effect depending on the extent to which increases in the polytropic exponent cause reductions in maximum strut stroke. Similar trends have been found in unpublished theoretical studies of landing-gear behavior.

#### Air-Compression Process Obtained During Drop Tests

In order to determine the type of air-compression process which actually occurred in these landing-gear tests, measurements of pneumatic pressure and strut stroke were analyzed to obtain values of the polytropic exponent  $n$  for the 30 impacts used in this investigation, which covered a range of vertical contact velocities from 0 to 11 feet per second. For each impact, corresponding instantaneous values of pressure ratio  $p_a/p_0$  and volume ratio  $v_0/v$  were plotted on logarithmic cross-section paper, as shown for a typical impact in figure 6. As can be seen, the data can be adequately represented by a straight line; thus the pressure-volume relationship obtained in the tests closely follows the polytropic law. A value for the polytropic exponent was obtained for each impact by measuring the slope of the straight line faired through the data. In the sample case shown in figure 6, this exponent was found to be 1.09. Figure 7 shows the measured values of  $n$  plotted as a function of contact velocity.

Since the lower rates of compression allow greater heat transfer, the low-velocity impacts might be expected to have smaller values of  $n$  than the higher velocity impacts in which the rate of compression is high. In general, as can be seen from figure 7, the measured values of  $n$  were

scattered between 1.01 and 1.10. The general trend of the data appears relatively independent of vertical velocity. The three test points obtained for contact velocities less than 4 feet per second, however, may indicate some tendency for the polytropic exponent to be smaller at low contact velocities. Unfortunately, the lack of data for the low contact velocities does not permit a closer study of the air-compression process in that region. Atomization of hydraulic fluid in the air chamber may influence the type of air-compression process obtained during an impact, but the accuracy of the data obtained during the present investigation does not permit a more detailed study of this factor. It appears that an average value of  $n$  equal to 1.06 can be used to represent the air-compression process which occurred during these tests. The deviation of the measured values of  $n$  from this average value did not exceed 5 percent.

### CONCLUSIONS

A brief investigation has been made to evaluate the importance of the type of air-compression process on the loads produced on an oleo-pneumatic landing gear during impact and to determine the type of air-compression process actually obtained during drop tests of a small landing gear. From this investigation the following observations can be made:

1. A simplified analysis to determine the effect which different air-compression processes might have indicates that the value of the air-compression exponent should have relatively little effect on the landing-gear loads throughout most of the impact. Near the end of the impact, however, differences in the air-compression process may have some effect on the total load, the effect depending on the extent to which increases in the polytropic exponent cause reductions in maximum strut stroke.

2. Values of the polytropic exponent ranging from 1.01 to 1.10 were obtained in the tests. For the practical range of vertical velocities the polytropic exponent appears to be relatively independent of vertical velocity. The air-compression process in these tests can be adequately represented by an average value of the polytropic exponent equal to 1.06.

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National Advisory Committee for Aeronautics  
Langley Field, Va., June 14, 1951

## REFERENCES

1. Batterson, Sidney A.: The NACA Impact Basin and Water Landing Tests of a Float Model at Various Velocities and Weights. NACA Rep. 795, 1944.
2. Milwitzky, Benjamin, and Lindquist, Dean C.: Evaluation of the Reduced-Mass Method of Representing Wing-Lift Effects in Free-Fall Drop Tests of Landing Gears. NACA TN 2400, 1951.

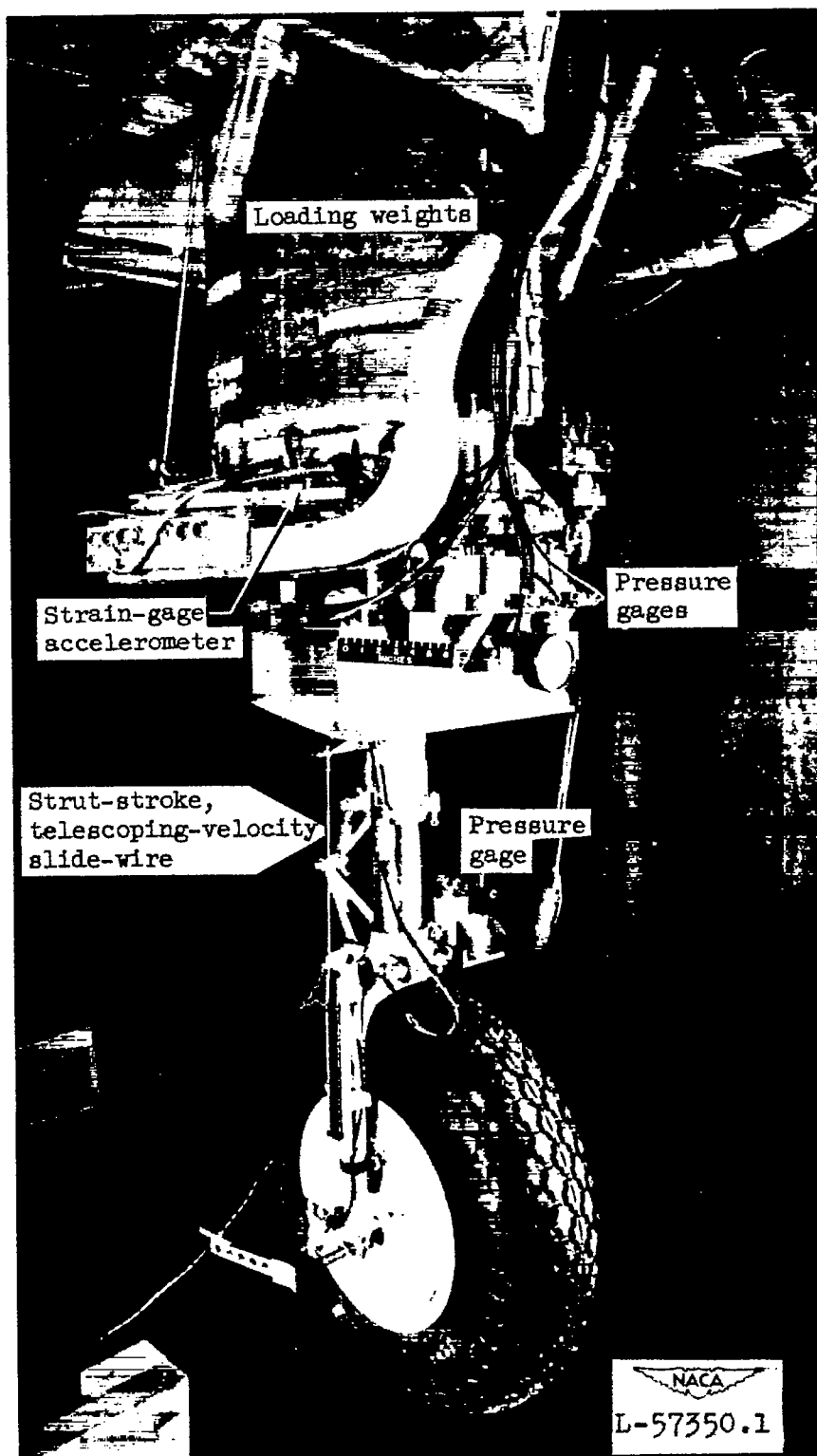


Figure 1.- Front view of landing-gear strut attached to boom in Langley impact basin.

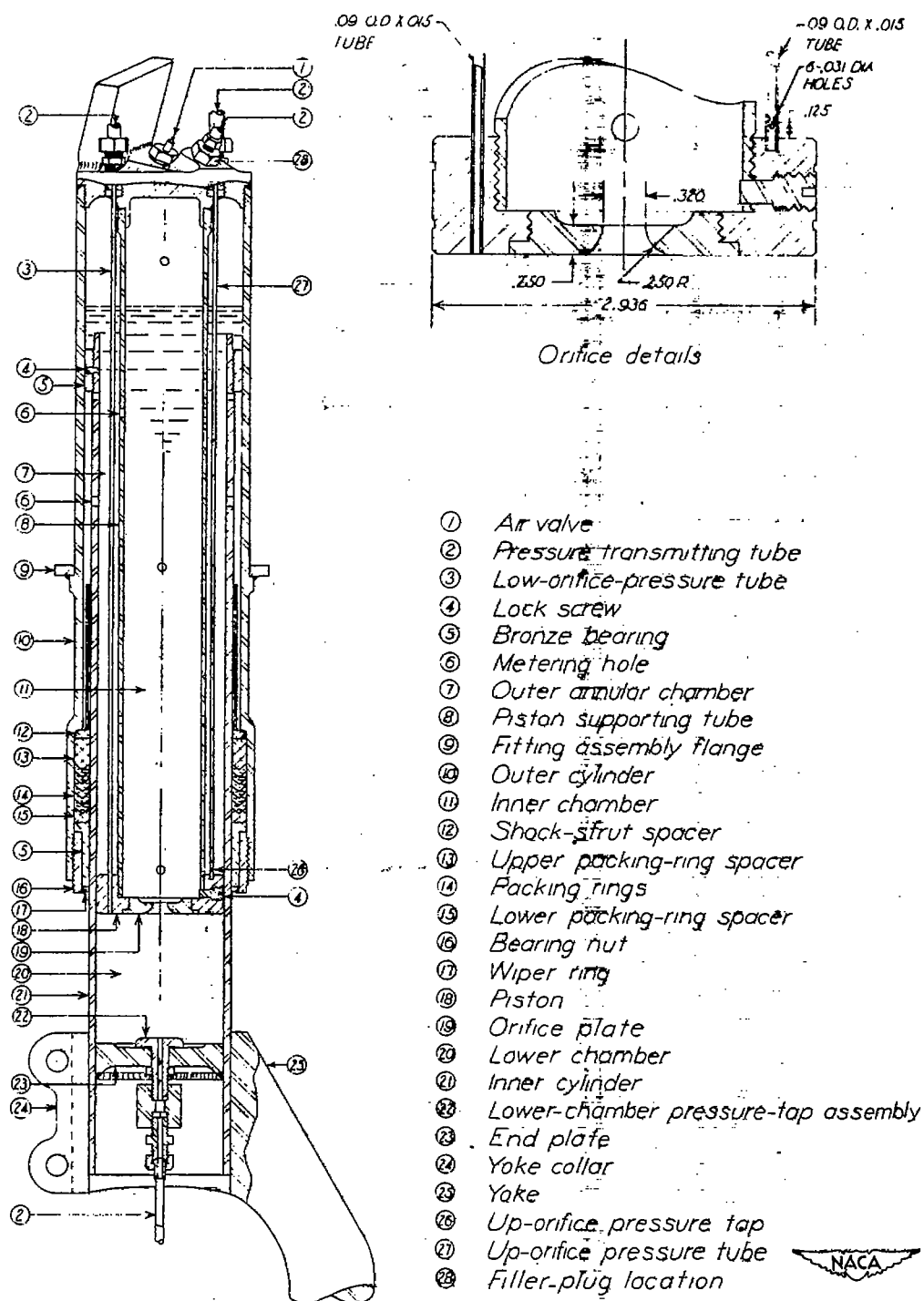


Figure 2.- Cross section of landing-gear strut tested in Langley impact basin.

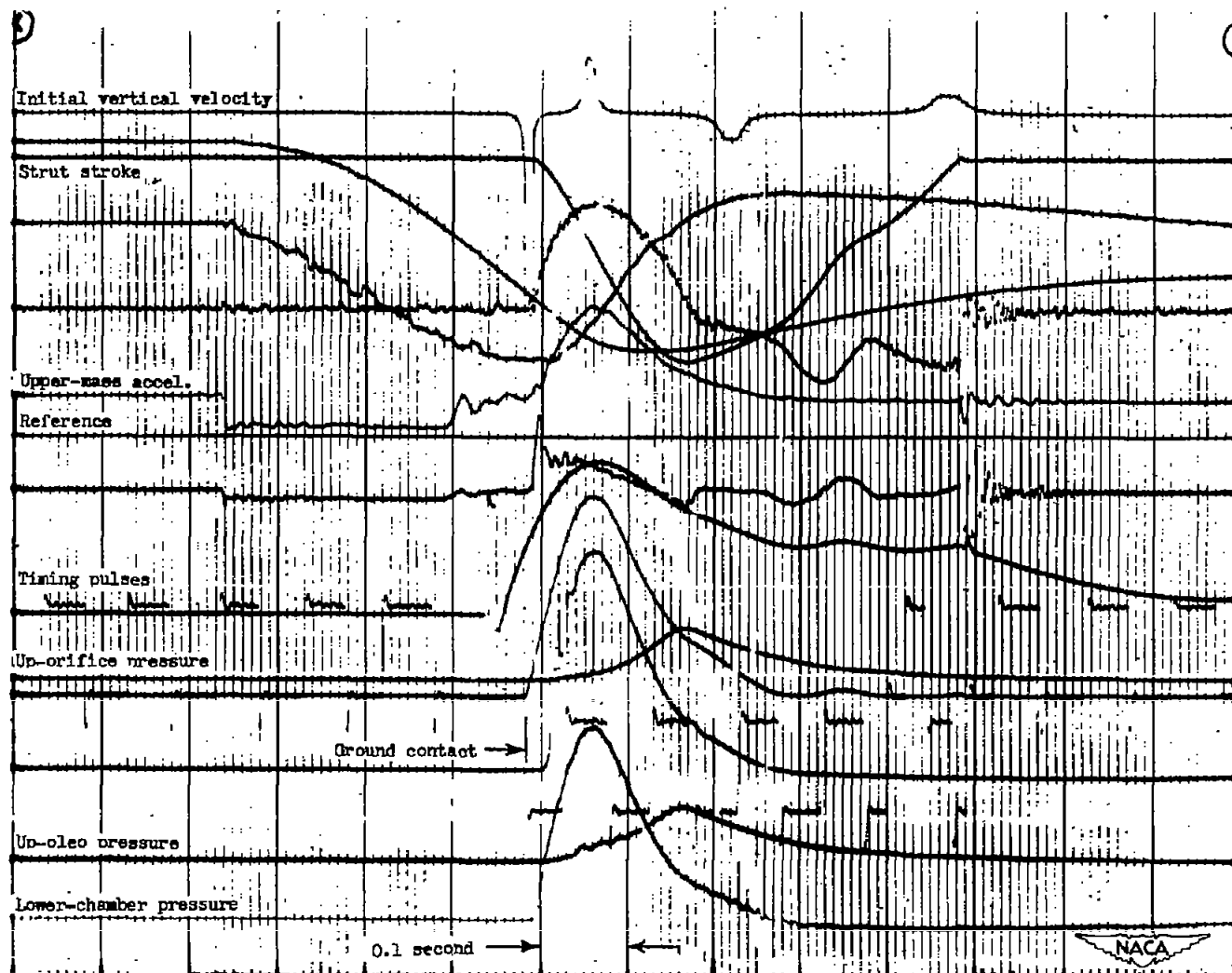


Figure 3.- Typical oscillograph record obtained during test in the Langley impact basin.

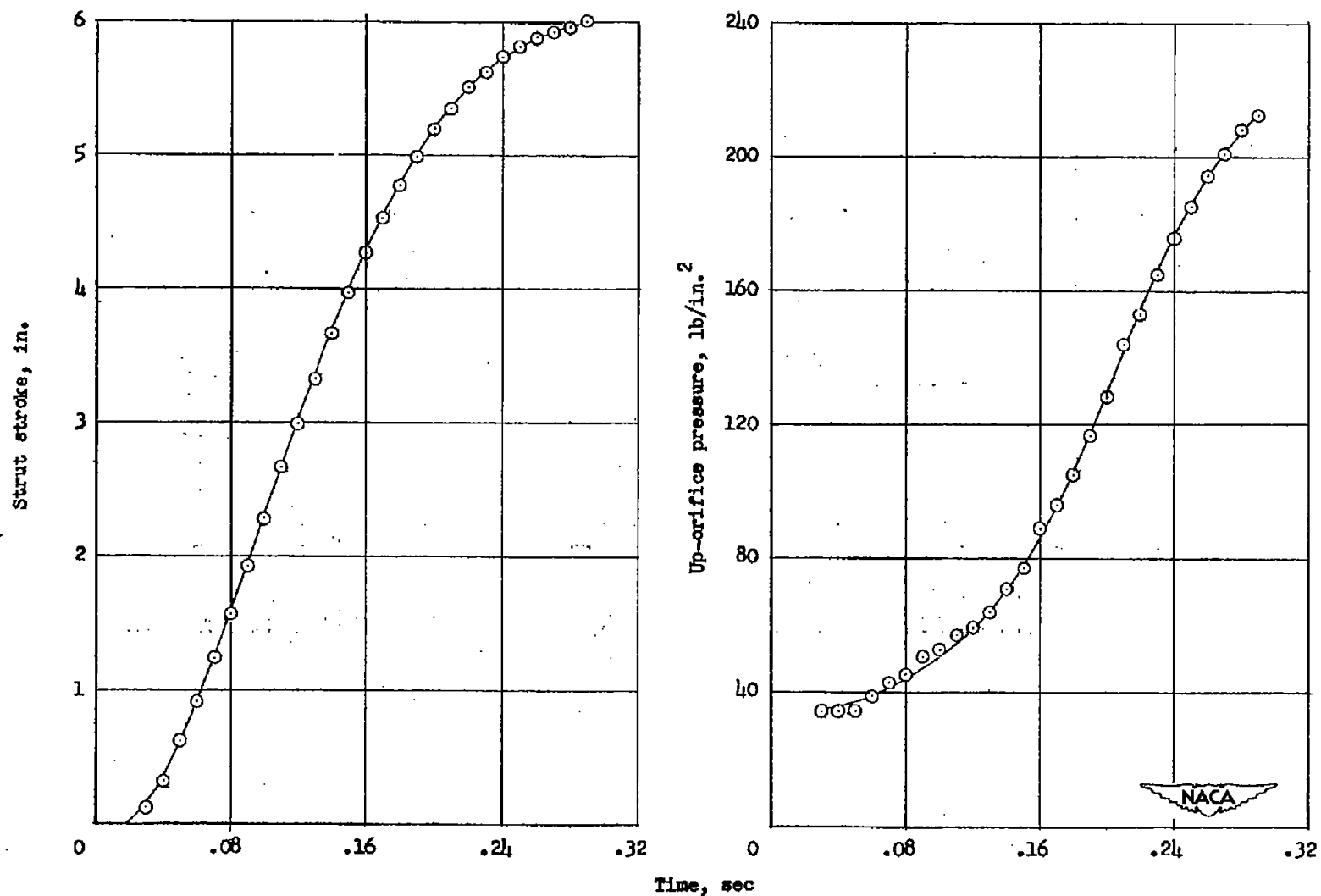


Figure 4.- Relationship between pneumatic pressure and strut stroke for a typical impact.

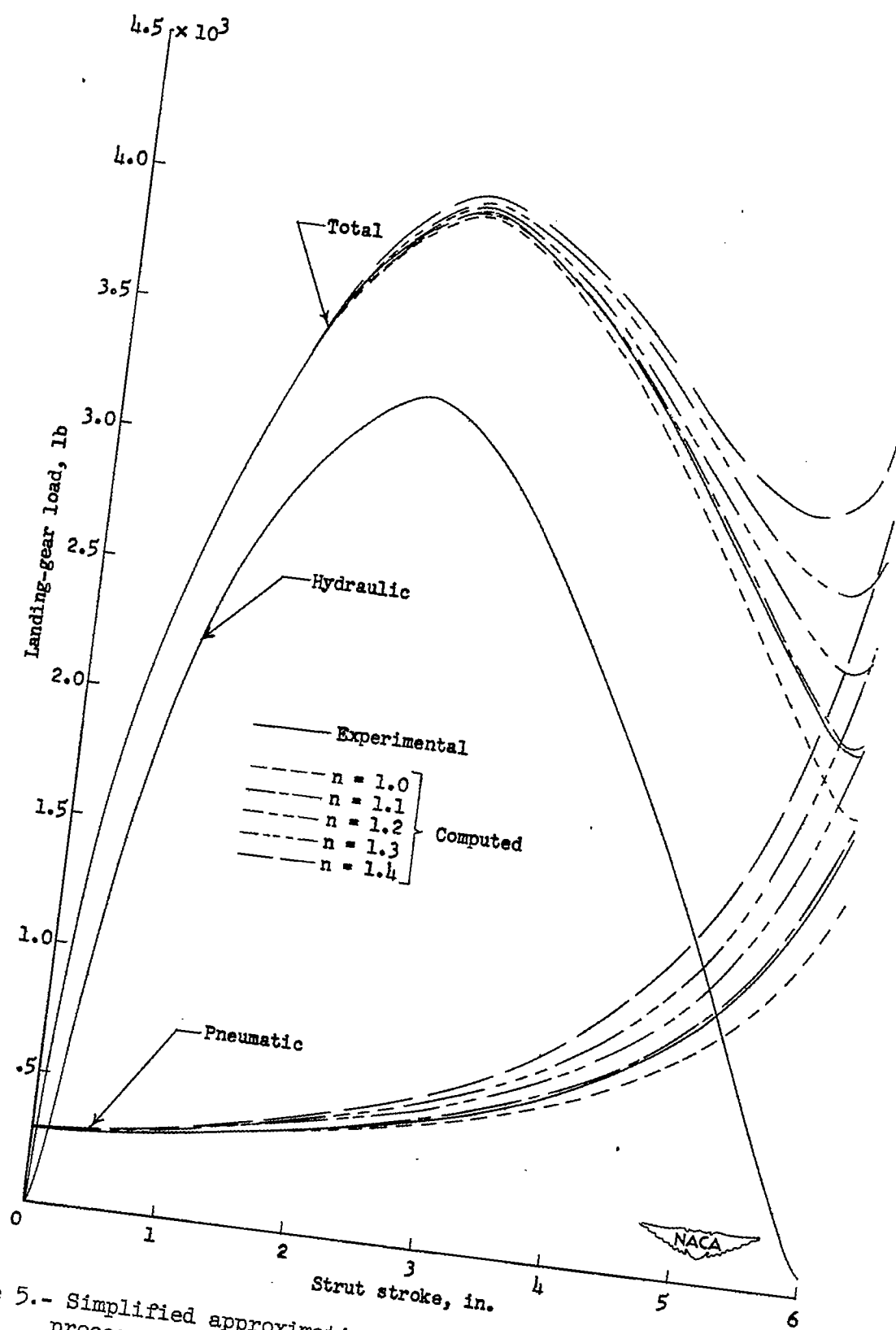


Figure 5.- Simplified approximation of the effect of the air-compression process on landing-gear load for a typical impact.



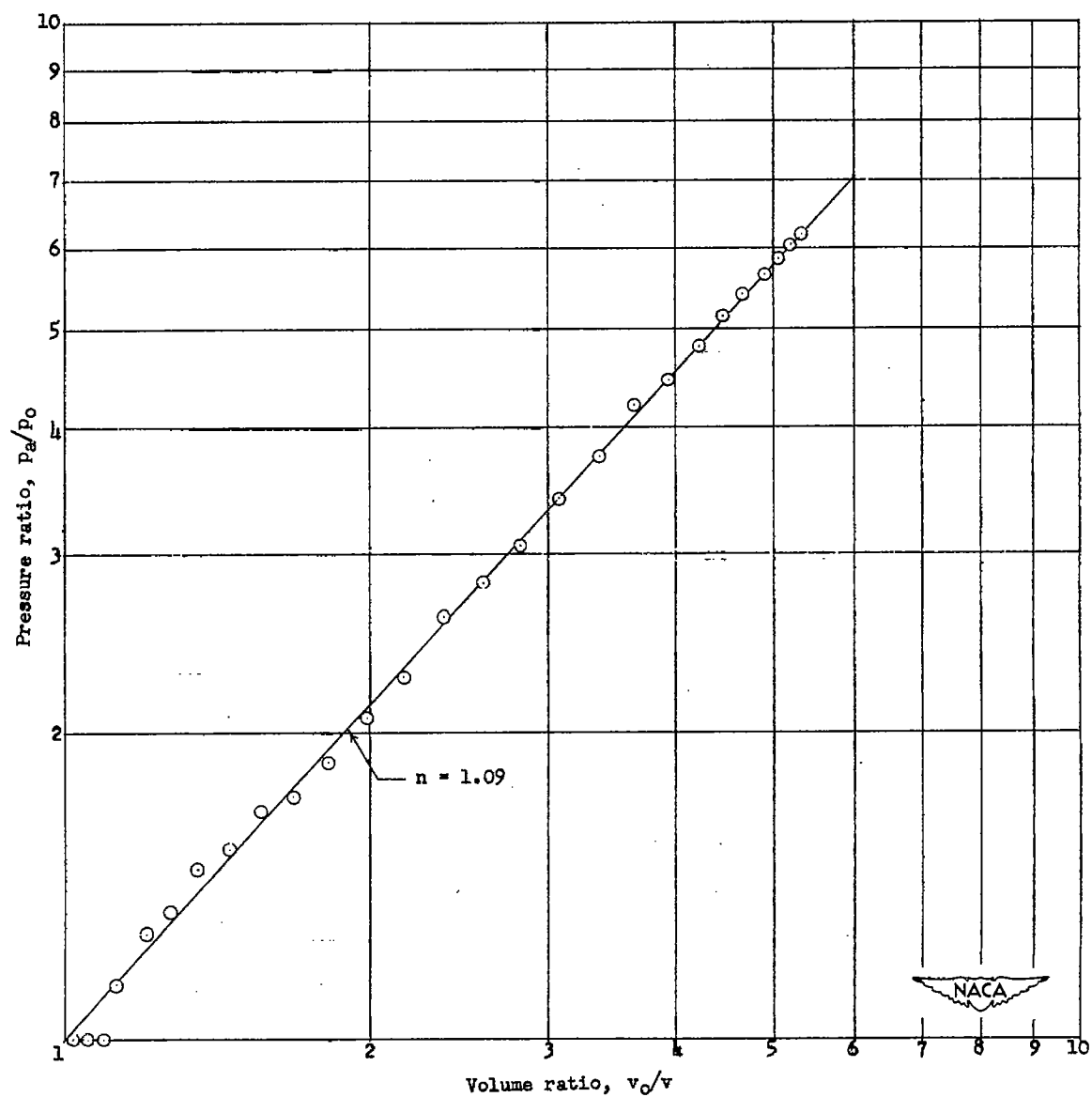


Figure 6.- Experimental variation of pressure ratio with volume ratio for a typical impact.

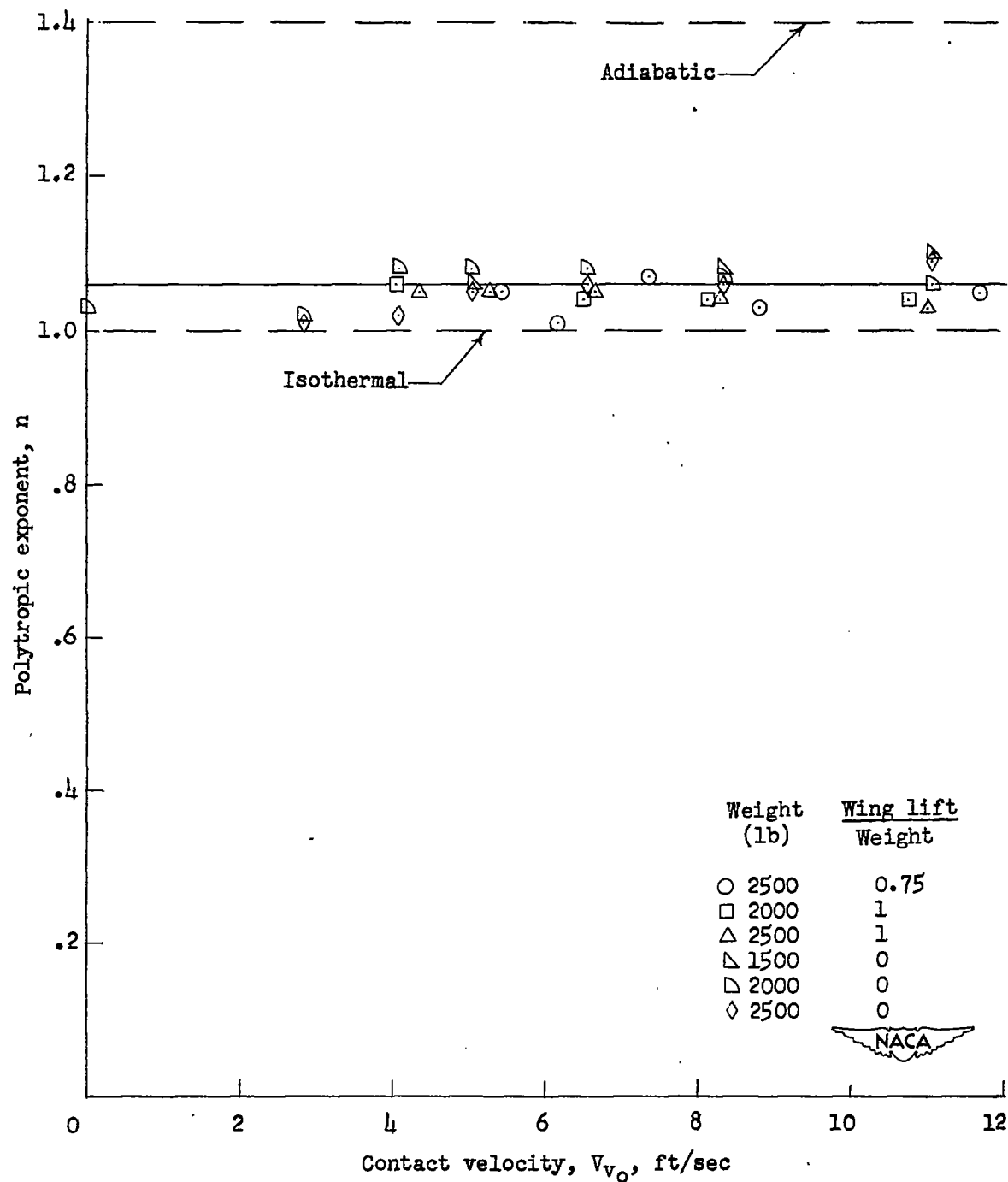


Figure 7.- Experimental variation of polytropic exponent with initial contact velocity.